SEDIMENT PRODUCTION FROM A CHAPARRAL WATERSHED IN CENTRAL ARIZONA

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ABSTRACT

Sediment production from two chaparral watersheds in central Arizona during a period of heavy winter rainfall in 1978 was compared with sediment production over a 14-year period (1964-78). Results indicate sediment production from chaparral is primarily the result of seasonal periods of heavy precipitation and runoff and not from ephemeral summer rainstorms. Sediments from 300 acres (122 ha) above a newly constructed stock watering tank were produced within a few days time in the late winter of 1978 at an accelerated annual rate of 41.1 ft^3/acre (2.9 m^3/ha). The sediments came mostly from cutting in channel alluvium in upstream tributaries where the sediments are presumed to have accumulated from downslope creep, dry ravel, and overland flow produced by ephemeral, convective rainstorms. The accelerated rate of sediment production was more than 4 times the average annual rate of 9.8 ft^3/acre (0.7 m^3/ha) determined from 14 years of cumulative sediment deposits in a stock tank constructed in 1964.

INTRODUCTION

Sediment production and transport from chaparral watersheds in central Arizona is a complex process, primarily dependent on periods of heavy precipitation. The ephemeral rainstorm in central Arizona is an individual precipitation event, usually in summer and early fall, and generally convective in nature. The ephemeral rainstorm is often intense, of short duration, and may generate sufficient overland flow to dislodge and transport soil from chaparral covered slopes to small upstream tributaries. The flows dissipate, dropping their sediment loads upon entering the flatter, dry channels. Only unusually heavy storms of this type produce enough runoff to carry sediment for any appreciable distance downstream.

Heavy seasonal precipitation, on the other hand, will exceed the storage capacity of the soil and produce flow rates capable of transporting large amounts of sediment. In central Arizona this seasonal precipitation usually is in winter and early spring in one or more cyclonic storms, often occurring in rapid succession.

The exact impact of these two precipitation regimes on sedimentation rates and processes is not well understood for chaparral watersheds in central Arizona. This paper examines the hypothesis that sediment production from chaparral watersheds in central Arizona is primarily the result of seasonal periods of heavy precipitation and runoff and is not primarily from ephemeral rainfall. While this hypothesis may appear to be in conflict with results of some investigators, discrepancies may be due to differences in soils and vegetation and the interpretation of results of small catchment and plot studies. For example, some early research from the Sierra Ancha Experimental Watersheds (USDA Forest Service 1953) indicates most soil loss from chaparral slopes occurs during summer months. It was not clear in the research report what happened to the sediments after they reached the channels, although it was determined that "the surface runoff waters are absorbed by the many small drainage channels and largely evaporate before the next storm occurs and therefore are an ineffective source of streamflow."

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Boster and Davis (1972), citing other research in and near the Sycamore Creek Watershed, state that 85% of the on-site soil movement is in response to summer rainstorms, while runoff occurs mostly in response to winter rains. Other evidence to support the hypothesis is available from research in chaparral watersheds in southern California. Measurements of sediment production in the San Dimas Experimental Forest indicate sediment transport and deposition result from large, infrequent streamflows following heavy winter precipitation (Rice 1974). Wolman and Miller (1960) discovered that because of the wide year-to-year variation in rainfall, large winter storms occurring once every 5 years or less are responsible for moving approximately 40-60% of the sediments produced on chaparral watersheds.

STUDY OBJECTIVES

Study objectives included the measure and evaluation of relatively long term (14 years) and short term (seasonal) sediment production from two small chaparral covered watersheds. Additional information was sought on particle size distribution and mechanism of transport (suspended or bed load). To the extent possible, the source of sediment was traced to the channels and slopes. However, no quantitative measurements were made of channel cutting and soil losses from the slopes.

RESEARCH AREA

The study area lies within the Battle Flat Watershed approximately in the center of the Bradshaw Mountains in central Arizona. The Battle Flat Watershed has a median elevation of 5,355 feet (1,633 m) and consists of several contiguous subwatersheds. The area drains into Turkey Creek and the Agua Fria River. Water yield is generally intermittent with streamflow beginning in early winter during wet years and continuing through May or June. In dry years little or no flow occurs. Mean annual precipitation in the Battle Flat watershed is approximately 23 inches (584 mm) with 15-20% occurring as snow.[1/] Precipitation generally results from cyclonic storms in winter and local convective storms in the summer. Mean daily temperature is approximately 59° F (15° C) with an annual maximum range from -21° F to 103° F (-29° C to 39° C).

The two subwatersheds under examination together occupy 435 acres (176 ha) in the northwest portion of Battle Flat. They are hereafter referred to as the south watershed (300 acres) (122 ha) and the north watershed (135 acres) (55 ha). The general geologic composition of these watersheds is described by Anderson and Blacet (1972) as massive bedded crystaline tuff with recent gravels along stream beds. Aspect is generally southeast, and slopes range from 15-40% with some as high as 60%. Elevations range from 5,200 to 5,800 feet (1,586-1,769 m) above sea level.

Soils on the two watersheds are similar and include Moano gravelly loam and Moano-Lynx association in the areas of lower elevation and Moano very rocky loam on the upper slopes.[1/] Vegetation is dense with shrub crown cover approximately 75-80%. The three separate vegetative associations include mixed chaparral of localized emory oak (Quercus emoryi) with alligator juniper (Juniperus deppeana) overstory, manzanita (Arctostaphylos pungens) - dominated chaparral, and a mixed fire succession association locally dominated by shrub live oak (Quercus turbinella), apache plume (Fallugia paradoxa), and occasionally yerba santa (Eriodictyon angustifolium).

The study watersheds are estimated to yield on the average about 1 inch of water (5% of the precipitation). This amounts to an annual production of 36 acre-feet (44,400 m^3) of water. In wet years much larger amounts are yielded, and in dry years very little. The water enters the stream by subsurface flow through the soil mantle and as runoff over the soil surface. In years of above normal precipitation, subsurface flow predominates over surface runoff (overland flow), and streamflow may extend into summer. Even after surface flows in channels cease, subsurface drainage may continue for a time through deep channel alluvium that may exceed 9 feet in depth. Loss of ground water in the study watersheds is prevented, probably by bedrock of low permeability.

Two stock watering tanks at the base of the watersheds were constructed by placing earth dams across the channels (figures 1 and 2). These small reservoirs are usually dry by mid summer. The lower stock tank was constructed in 1964 and, until 1977, received all sediment yields from both watersheds. In 1978 it received only sediment from the north watershed. The new tank, constructed in 1977 approximately 700 feet upstream from the old tank, receives sediment only from the south watershed.

[1/] Environmental Analysis Report for the Battle Flat Chaparral Pilot Application Project. Prescott Nat. For., Ariz., Unpubl. Rep. 59 p. 1978.

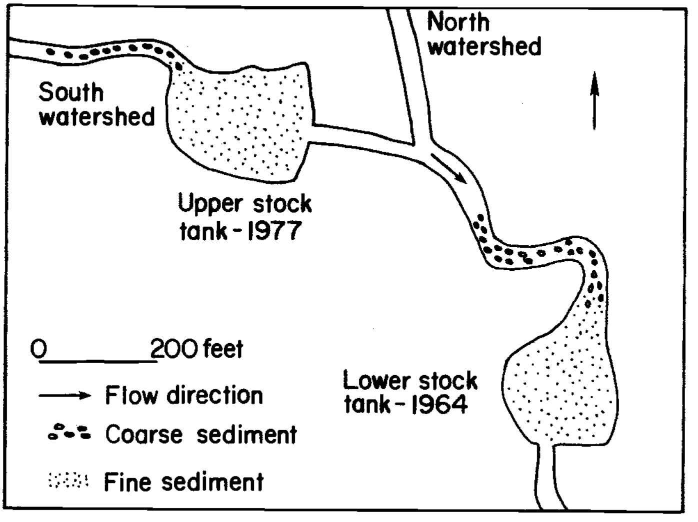

Figure 1.--Stock tanks below the study watersheds.

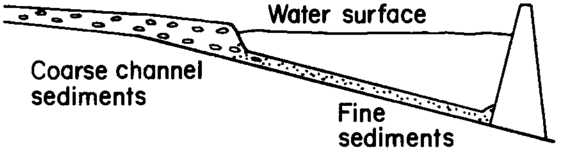

Figure 2.--Idealized cross section of stock tank.

Two distinct sediment deposits are associated with each of the stock tanks (figures 1 and 2). An elongated deposit of course grained material was deposited in the stream channels at the upper ends of the tanks, while fine grained sediments were deposited in the bottoms of the tanks.

METHODS

The volume of sediment deposited in the stream channels and stock tanks was determined from surface area measurements and depth samples. The width of the sediment deposits was measured at cross sections 25 feet apart. The average depth of sediment was measured at several places along each of the cross sections using soil augers, shovels, and soil coring devices.

The base of the sediment deposits was identified by a distinct stratigraphic contact, either an immediate change in lithology from unconsolidated fine and/or coarse grained sediments to the consolidated alluvial material of the old stream bed or a dark layer consisting of decomposed organic material accumulated prior to the deposition of sediments. The total volume of sediment deposited in the stream channels and stock tank bottoms was determined by multiplying the depth of the sediment layer by the surface area of the deposit. Volume of the deep, narrow stream channel deposits was calculated separately from the volume of the shallow deposits of the stock tank bottoms to increase accuracy. The dates of construction of the two stock tanks and the total volume of sediment deposition provide the rate of sediment yield for the study watersheds.

Sediment samples from the new stock tank and its immediate upstream channel were collected at the same 25-foot intervals as the sediment width and depth measurements. These samples were oven dried for a period of 24 hours at 105° C. The samples were then placed in 8-inch, U.S. Standard sieves on the Ro-Tap shaker in order to classify them according to the Udden-Wentworth grade scale.

RESULTS AND DISCUSSION

The total volume of sediments deposited in the upper stock tank was 12,325 ft^3 (349 m^3). Eighty percent of the sediment was deposited along the immediate upstream channel where water entered the pond, and 20% was distributed more uniformly over the bottom of the tank. The sediment originated from the 300 acres in the south watershed during a short period of heavy rainfall in the winter of 1978. The accelerated or short term annual rate of sediment production was 41.1 ft^3/acre (2.87 m^3/ha).

The volume of sediments deposited in the lower stock tank and its immediate upstream channel was 47,405 ft^3 (1,342 m^3), including the sediment produced by the north watershed in 1978. Adding the 1978 deposit from the upper tank, the sediment production from both watersheds from 1964 through the spring of 1978 is 59,730 ft^3 (1,692 m^3), yielding a mean annual rate of 9.8 ft^3/acre (0.7 m^3/ha).

Seventy-three percent of the sediment sampled from the stream channel deposits immediately above the upper stock tank was coarse sand or larger with cobbles and pebbles dominating (figure 3); 69% of the sediment in the thin layer over the bottom of the upper stock tank was medium sand or smaller with fine sand dominating.

Precipitation 2/ on the study area was nearly three times normal for the four months ending March 31, 1978 (table 1). The previous year was dry, with little or no runoff. Soil water recharge began with the first significant rains in late December and continued until the watersheds began to yield water sometime between February 27 and March 4. Although 17.5 inches (444 mm) of rain had fallen by mid February, no overland flow or streamflow resulted from these earlier storms. However, both stock tanks were full and overflowing when observed on March 4, after 4 days of nearly continuous rainfall. These rains added 12.0 inches (305 mm) of water, and rains on March 5-7 added another 1.9 inches (48 mm).

On March 9 combined flow from the two watersheds was estimated at 1 cfs (0.03 m^3/sec) by measuring the stream cross section and flow velocity where it enters the lower tank. Peak flows probably occurred on March 1 or 2 during the heaviest part of the storm. From high water marks visible

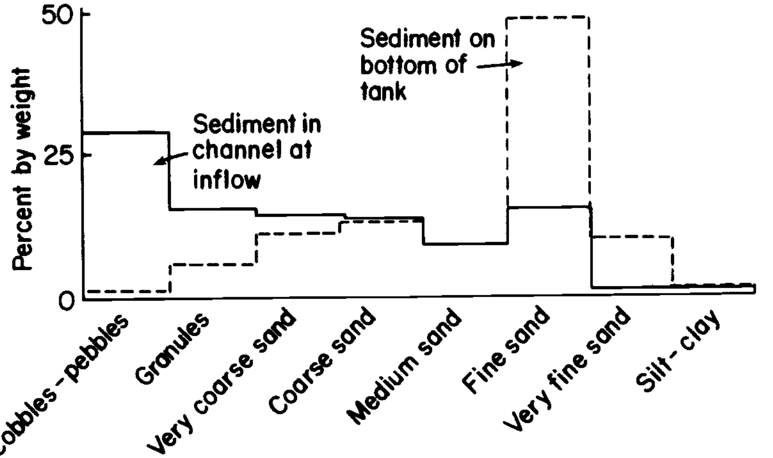

Figure 3.--Particle size distribution of sediment from a chaparral covered watershed by location of deposit within the stock tank.

2/ Precipitation data are for Crown King 7 miles south at 6,000 feet elevation. The study area receives an estimated 10-20% less precipitation than the amounts shown here.

Table 1.--Inches of daily precipitation at Crown King, Ariz. The study watersheds are located 7 miles north and at slightly lower elevations, where precipitation is lower by an estimated 10-20%.

Day	Dec. 1977	Jan. 1978	Feb. 1978	Mar. 1978
1			.10	4.87
2				3.38
3				2.03
4				
5		.36		1.43
6			.50	.37
7			.34	.08
8			.20	
9			.02	
10		1.20	.29	.08
11		1.05	2.80	
12			.95	1.05
13			.05	
14			.15	
15		2.90		
16				
17		1.70		
18				.01
19	.02	.30		
20		.50		
21		.10		
22	.02			1.11
23				.05
24				
25				
26				
27	.30		.23	
28	.25		1.50	
29	1.10			
30	.65	.01		
31	___	1.59	___	.06
Monthly totals	2.34	9.71	7.13	14.52
Cumulative totals	2.34	12.05	19.18	33.70

on March 9, peak inflow to the lower stock tank was estimated to have exceeded 11 cfs (0.31 m^3/sec). On April 27 combined flow from the two watersheds was estimated at 0.2 cfs (0.006 m^3/sec), and by May 22 it was less than one-half this amount. By mid June the channels were dry.

Although the exact time of sediment deposition in the upper tank could not be determined, it is assumed that transport and deposition took place primarily during periods of high flow, which lasted a few days at most. It is known that the drainage channels were dry until after February 27, when the last of the big storms began. By March 9, flows in these channels were only slightly turbid, and little bed material was moving. The sediment deposits were visible at the upper ends of both stock tanks, but no measurements were possible until the water subsided. None of the storms after March 9, and prior to sediment measurement in June, were large enough to cause significant new erosion on the slopes or in the channels. Therefore, it was concluded that the bulk of sediment transport and deposition took place within a few days, most likely March 1-3 when rainfall was heaviest.

Movement of sediments from chaparral slopes to upstream tributary channels and eventually out of the watershed is a complex process, which is primarily dependent on amounts and intensities of precipitation. Soil particles are initially transported from slopes to upstream tributaries through the processes of downslope soil creep, dry ravel, and overland flow (Hibbert et al. 1974). Sediments accumulate in the upstream tributaries until a streamflow of sufficient magnitude occurs to transport the sediments to downstream channels and out of the area. Limited streamflows from most summer convective storms are not large enough to do this. Only rarely are summer storms big enough to generate and sustain the quantity of overland flow required to transport large amounts of sediment far downstream (the exception is immediately after chaparral wildfires, when overland flow occurs much more readily as a result of a fire-induced nonwettable layer near the soil surface) (DeBano 1971, Scholl 1975). A streamflow of sufficient magnitude and duration to transport the sediments to downstream channels and out of the area is more likely to be produced by a series of intense winter storms that result in above normal precipitation.

Sediments in the upstream tributaries of the study watersheds had been accumulating for an unknown period of time prior to the initiation of streamflow on about March 1, 1978. The high volume of this flow cut and transported the accumulated sediments from the upstream channels to the stock tanks. These high flows originated primarily from subsurface flows after saturation of the soil mantle, and continued into June. Observations made on the watershed after the early March activity indicated that rilling caused by overland flows occurred only at a few locations during periods of intense precipitation.

The coarse sediments, including gravel carried as bed load, were deposited in the channels immediately above the stock tanks. The finer grained sediments were transported as suspended load and were carried into the two stock tanks as they rapidly filled with water. The fine material was deposited in thin layers on the bottom of the tanks.

The large amount of sediments deposited in the stock tanks below the study watersheds in response to the heavy winter rains in 1978 supports the hypothesis that sediment production from chaparral watersheds in central Arizona is primarily the result of heavy winter precipitation and runoff and not from ephemeral rainfall. The accelerated rate of sediment production was 4.2 times the mean annual rate for 14 years, including 1978. Fourteen years is too short a period to establish a reliable long-term erosion rate for these watersheds when yearly sediment production is known to vary from nothing in some years to at least the amount (41.1 ft^3/acre) observed in 1978. The expected frequency of seasonal precipitation of the magnitude experienced in the winter of 1977-78 on Battle Flat is not known. However, precipitation records at Crown King show four winter periods between 1964 and 1977 when precipitation exceeded the approximately 20 inches (508 mm) required to initiate heavy flows by March 1 in the 1977-78 period:

1. November 1964-April 1965	24.1 inches (612 mm)
2. November 1965-February 1966	24.4 inches (620 mm)
3. November 1967-March 1968	23.6 inches (599 mm)
4. October 1972-March 1973	27.1 inches (688 mm)

How many of these wet periods produced high flows is not known; nor can we tell how much runoff might have been caused by summer storms on these watersheds. The Crown King rain gage is too far away to use for estimating summer storm intensities and amounts. However, since the accelerated rate of sediment production was more than four times the mean annual rate for the entire period, it seems reasonable to attribute the bulk of the production prior to 1978 to the four known wet periods.

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